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February 10, 1967

LOGIC CHANGES TO THE TWO-IMPULSE PROCESSOR FOR PROJECT APOLLO

By Jerome A. Bell
Rendezvous Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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CONTENTS

LOGIC CHANGES TO THE TWO-IMPULSE PROCESSOR FOR PROJECT APOLLO

By Jerome A. Bell

SUMMARY AND INTRODUCTION

Project Apollo has necessitated changing the existing two-impulse display, which requires corresponding changes to the logic of the present two-impulse processor. This internal note presents these changes by revising references 1, 2, and 3. (Ref. 1 revised ref. 2.) An attempt has been made to be consistent with reference 1 deleting, modifying or adding logic where required.

DISPLAY PARAMETERS DELETED

The new two-impulse display deletes the following parameters (symbols defined in ref. 2):

a. Burn time of each maneuver, (ΔT_B).

b. Burn-initiation time of each maneuver (GET_B and GMT_B).

c. Elapsed time from N_{SR} (ET NSR)

d. Gemini platform incremental velocity components (ΔV_X, ΔV_Y, and ΔV_Z).

e. Thruster used for each display.

DISPLAY PARAMETERS ADDED

The new two-impulse display adds the following parameters (symbols used in flow chart):

a. Pitch angle between the window on the active vehicle and the active vehicle's body X-axis ($\Delta\phi$).

b. Time interval between the first and second maneuver (ΔT_R).

c. Central travel angle of the passive vehicle between the first and second maneuver (ωt).

d. Impulsive time for each maneuver (GET and GMT).

e. Elevation angle between the active vehicle's local horizontal and the earth's horizon for each maneuver (ϕ_H).

f. Impulsive components of each maneuver in external ΔV coordinates $\left(\Delta V_{X_{E\Delta V}}, \Delta V_{Y_{E\Delta V}}, \text{ and } \Delta V_{Z_{E\Delta V}}\right)$.

g. Pitch and yaw of active vehicle's body so that the window is along a given line of sight for each maneuver (ϕ_{view}, ψ_{view}).

h. Incremental velocity components for each maneuver in active vehicle's body coordinate system when window is along a given line of sight (V_{80}, V_{81} and V_{82}).

i. Relative print prior to each maneuver. This includes the azimuth and elevation angles of the passive vehicle from the active vehicle (ψ_R, ϕ_R); it also includes the down range, and vertical and lateral displacement of the active vehicle from the passive in a curvilinear coordinate system with the positive axes identical to the external ΔV coordinate system (X_C, Y_C, and Z_C).

LOGIC CHANGES TO REFERENCE 1

A revision of the detailed flow chart of Appendix II of reference 1 is presented in Appendix A of this note. The logic changes are as follows:

a. Set the number of lines of relative print to 3 if the data is required prior to the first maneuver or 4 if the data is required prior to the second maneuver.

b. Compute relative displacement (X_C, Y_C, Z_C) of active vehicle from passive vehicle in curvilinear coordinate system following the computation of target azimuth and elevation angles.

c. Set logic to operate as an active-passive nomenclature instead of vehicle 1 being target and vehicle 2 being chaser.

A revision of the detailed flow chart of Appendix III, reference 1 is presented in Appendix B. The changes are listed below. Page numbers refer to Appendix III, reference 1.

a. Compute each impulsive maneuver in external ΔV coordinates $\left(\Delta V_{X_{E\Delta V}}, \Delta V_{Y_{E\Delta V}}, \text{ and } \Delta V_{Z_{E\Delta V}}\right)$.

b. Set engine cant angles of the active vehicle (ε and ε').

c. Delete the computation for burn duration and burn initiation time (page 1).

d. Delete all logic between the impulsive directional pitch and yaw computation (page 2) and "K = K + 1" (page 3).

e. Delete the "L_C: 1" test; Go directly to "4" if K >2 (page 3).

f. Delete the terminal phase test (page 4).

g. Compute approach data prior to each maneuver.

h. Compute both the look angles to the target and to the horizon (ϕ_T, ψ_T, ϕ_H, ψ_H).

i. Choose whether the vehicle is to be pointed at the horizon or the target.

j. Compute velocity components for each maneuver in active vehicle body coordinate system when window is along a line of sight (V_{80}, V_{81}, and V_{82}).

k. Compute pitch and yaw of active vehicle's body for window to be along a given line of sight (ϕ_{view}, ψ_{view}).

l. Compute ΔV components to be applied in one direction at a time (X_{BR}, Y_{BR}, and Z_{BR}).

m. Delete all logic on page 7.

n. Compute acceleration of lateral thrusters assuming 2 quads fire (page 8).

o. Delete V_e computation (page 8).

p. Delete ε, Isp (page 8).

q. Change the "V_e:0" to V_{80} (K, NS):0.

r. Set logic to operate as an active-passive nomenclature instead of vehicle 1 being target and vehicle 2 being chaser.

INPUT CHANGES TO REFERENCE 1

The following input additions or deletions are required to reference 1:

a. "Kode" has been changed to denote pointing of vehicle (zero if at horizon, 1 if at target).

b. Delete T_{NSR}.

c. Delete cant angle array ($E_{IT,\ L}$).

d. Delete ullage times (ΔT_{ULL} and ΔT_{ULL_2}).

e. Delete thruster choice (IT_1 and IT_2). It is assumed the RCS will be used

f. Delete thrust and specific impulse array $\left(T_{IL,\ L}\text{ and }I_{SP_{IL,\ L}}\right)$.

It is assumed all RCS thrusters have equal thrust and specific impulse. Input the thrust and specific impulse ($T_{1,\ LC}$ and $I_{SP_{1},\ LC}$) of one of the active vehicles RCS thrusters.

g. Delete lateral thruster cant angles (E_{LAT}).

h. Delete thrust value for lateral thruster (T_{LAT}).

i. Delete attitude mode (ATT_1 and ATT_2).

j. Input number of quads to be used for x-axis thrusting (N_{QUAD} 2 or 4).

k. Input pitch angle between the window on the active vehicle and the active vehicle x-body axis ($\Delta\phi$). $\Delta\phi$ is positive if the x-body axis has to be pitched up in order for the window to be along a given line of sight.

CHANGES TO REFERENCE 2

In order to use the two-impulse processor (ref. 2), it is necessary to input either the times of both the first and second maneuvers (t_1 and t_2) or the time of the first maneuver (t_1) and the desired passive vehicle travel angle between the first and second maneuvers (ωt). The display format requires that both the time between the first and second maneuver (Δt_R) and the passive vehicle travel angle (ωt) to be displayed.

If the two maneuver times are input, $\Delta t_R = t_2 - t_1$ and $\omega t = N_T (t_2 - t_1)$ where N_T is the mean motion of the passive vehicle. If the time of the first maneuver and passive vehicle target travel angle is input, $\Delta t_R = \frac{\omega t}{N_T}$, where ωt is the input value.

CHANGES TO SUBROUTINE ROTATE

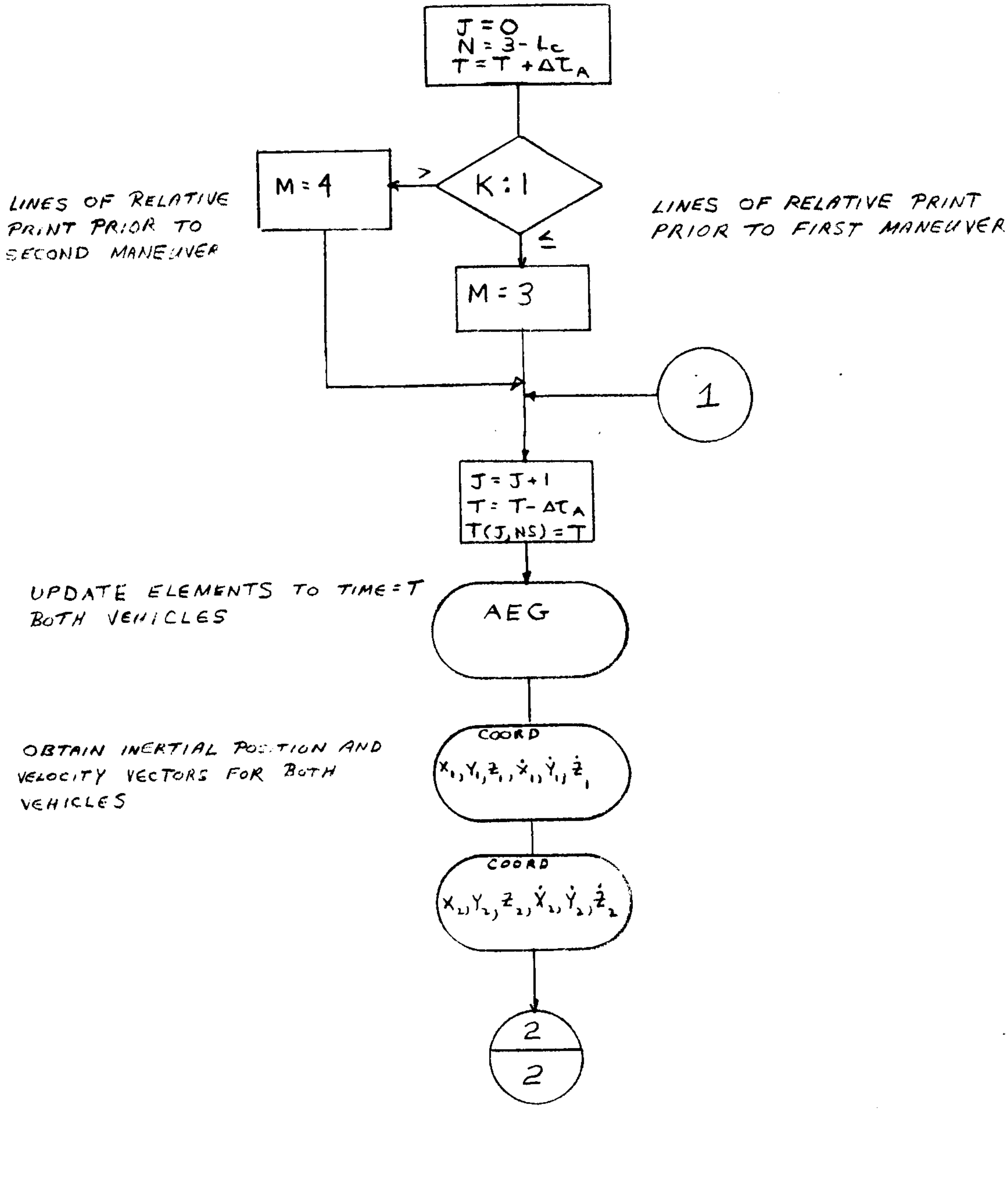
In modifying the two-impulse display for Apollo, it was necessary to modify Subroutine Rotate (ref. 3). A revised flow chart is included in Appendix C of the internal note.

It was advantageous in Gemini to assume that the active vehicle (vehicle 2) had a relative coordinate system in the direction of motion, down and to the left, while the passive vehicle (vehicle 1) had a relative coordinate system opposite the direction of motion, up and to the left. As long as vehicle 2 was the active vehicle, the relative azimuth and elevation to the target would be correct but if vehicle 1 was active, the computation of the angles would not apply without modification to the logic. All that was done to "rotate" was to make the coordinate system of vehicle 1 identical to that of vehicle 2.

APPENDIX A

REVISED LOGIC TO COMPUTE RELATIVE QUANTITIES FOR THE TWO-IMPULSE DISPLAY

APPENDIX A: REVISED LOGIC TO COMPUTE RELATIVE QUANTITES FOR THE 2-IMPULSE DISPLAY



2

RANGE

$$r = r(J,NS) = \left[(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2\right]^{\frac{1}{2}}$$

RANGE RATE

$$\dot{r}(J,NS) = \frac{\left[(X_2 - X_1)(\dot{X}_2 - \dot{X}_1) + (Y_2 - Y_1)(\dot{Y}_2 - \dot{Y}_1) + (Z_2 - Z_1)(\dot{Z}_2 - \dot{Z}_1)\right]^{\frac{1}{2}}}{r}$$

COMPUTE RELATIVE COORDINATES OF PASSIVE VEHICLE IN ACTIVE VEHICLE COORDINATE SYSTEM

ROTATE

X_4, Y_4, Z_4

LOOK ANGLES FROM THE ACTIVE VEHICLE TO THE TARGET (YAW & PITCH)

$$\psi_R(J,NS) = TAN^{-1}\left[\frac{-Z_4}{X_4}\right]$$

$$\phi_R(J,NS) = TAN^{-1}\left[\frac{-Y_4}{(X_4^2 + Z_4^2)^{\frac{1}{2}}}\right]$$

COMPUTE RELATIVE COORDINATES OF ACTIVE VEHICLE IN PASSIVE VEHICLE COORDINATE SYSTEM

ROTATE

X_4', Y_4', Z_4'

PHASE ANGLE BETWEEN PASSIVE AND ACTIVE VEHICLE IN PASSIVE VEHICLE PLANE POSITIVE IF ACTIVE VEHICLE LEADS

$$\Delta\theta = TAN^{-1}\left[\frac{X_4'}{R_N - Y_4'}\right]$$

CURVILINEAR COORDINATES OF ACTIVE VEHICLE FROM PASSIVE.

POSITIVE X_c = AHEAD

POSITIVE Z_c BELOW

POSITIVE Y_c RIGHT

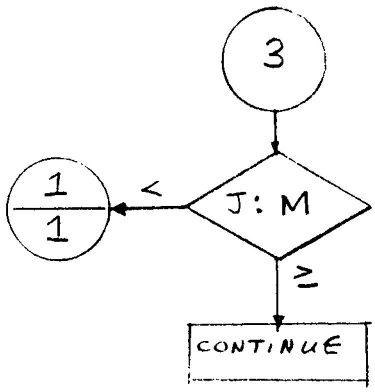
$$X_c(J,NS) = R_N \Delta\theta$$

$$Z_c(J,NS) = R_N - R_{Lc}$$

$$Y_c(J,NS) = -Z_4'$$

3

3


3
J : M
<
1
1
≥
CONTINUE

APPENDIX B

REVISED LOGIC TO COMPUTE THE TWO-IMPULSE DISPLAY QUANTITIES

APPENDIX B: REVISED LOGIC TO COMPUTE THE 2 IMPULSE DISPLAY QUANTITIES

START

IMPULSIVE ΔV IN EXTERNAL ΔV COORDINATES

$\Delta V_{x_{E\Delta V}}(1, NS) = \Delta\dot{X}_T$

$\Delta V_{Y_{E\Delta V}}(1, NS) = \Delta\dot{Z}_T$

$\Delta V_{Z_{E\Delta V}}(1, NS) = -\Delta\dot{Y}_T$

$\Delta V_{x_{E\Delta V}}(2, NS) = \Delta\dot{X}_R$

$\Delta V_{Y_{E\Delta V}}(2, NS) = \Delta\dot{Z}_R$

$\Delta V_{Z_{E\Delta V}}(2, NS) = -\Delta\dot{Y}_R$

INCREMENTAL VELOCITY COMPONENTS REQUIRED FOR SUBROUTINE "APPLY"

$\Delta V_x(1, NS) = \Delta\dot{X}_T$

$\Delta V_Y(1, NS) = -\Delta\dot{Y}_T$

$\Delta V_Z(1, NS) = -\Delta\dot{Z}_T$

$\Delta V_x(2, NS) = \Delta\dot{X}_R$

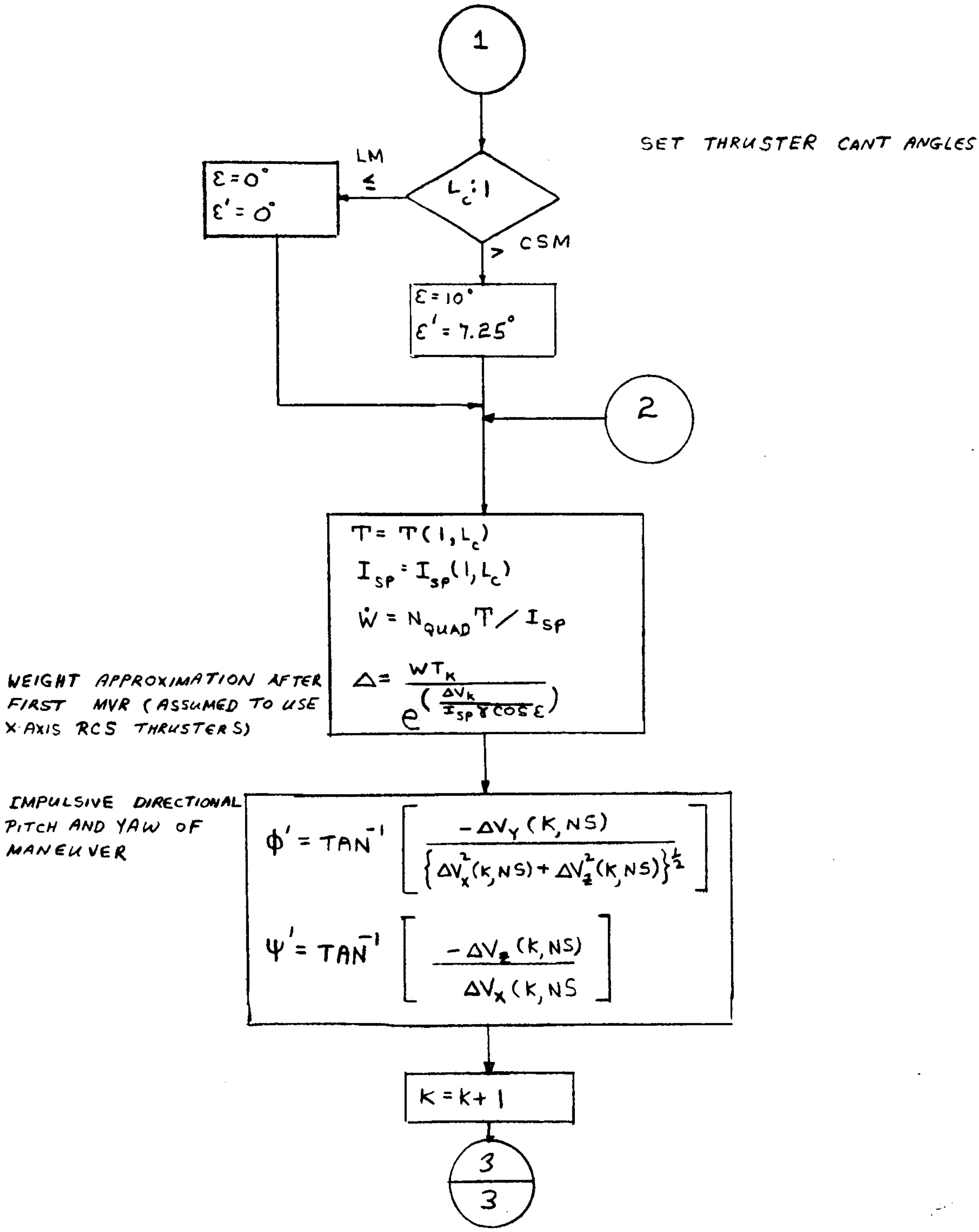
$\Delta V_Y(2, NS) = -\Delta\dot{Y}_R$

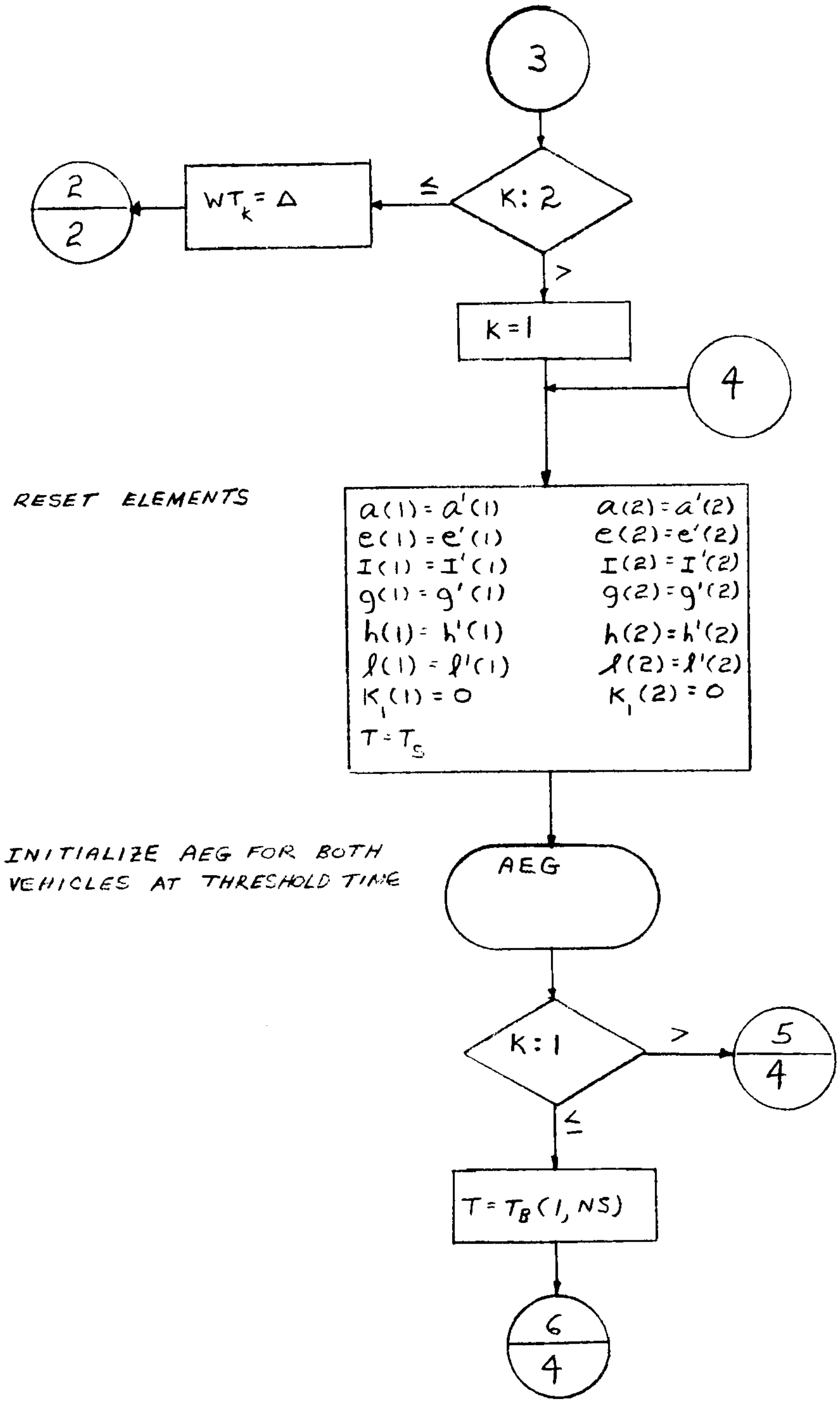
$\Delta V_Z(2, NS) = -\Delta\dot{Z}_R$

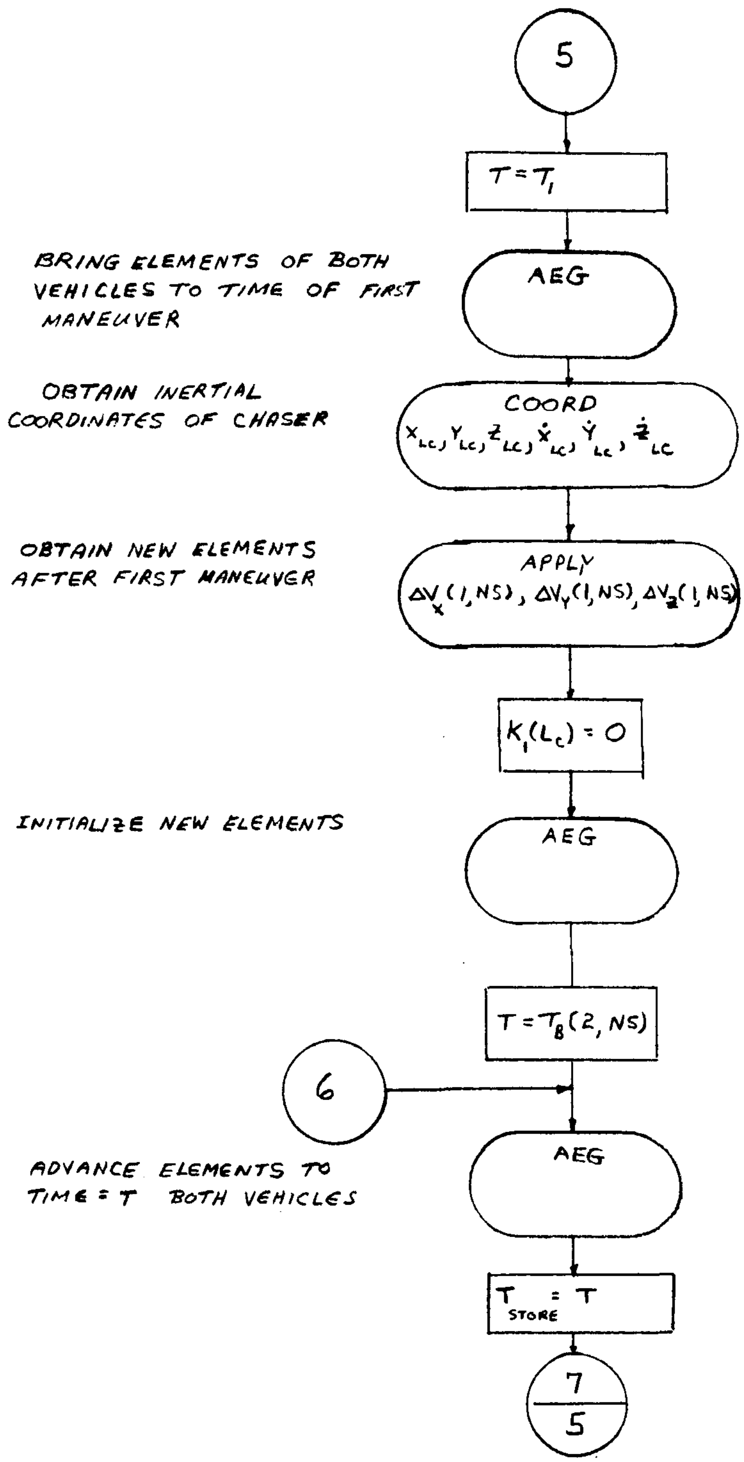
$WT_1 = WEIGHT(L_c)$

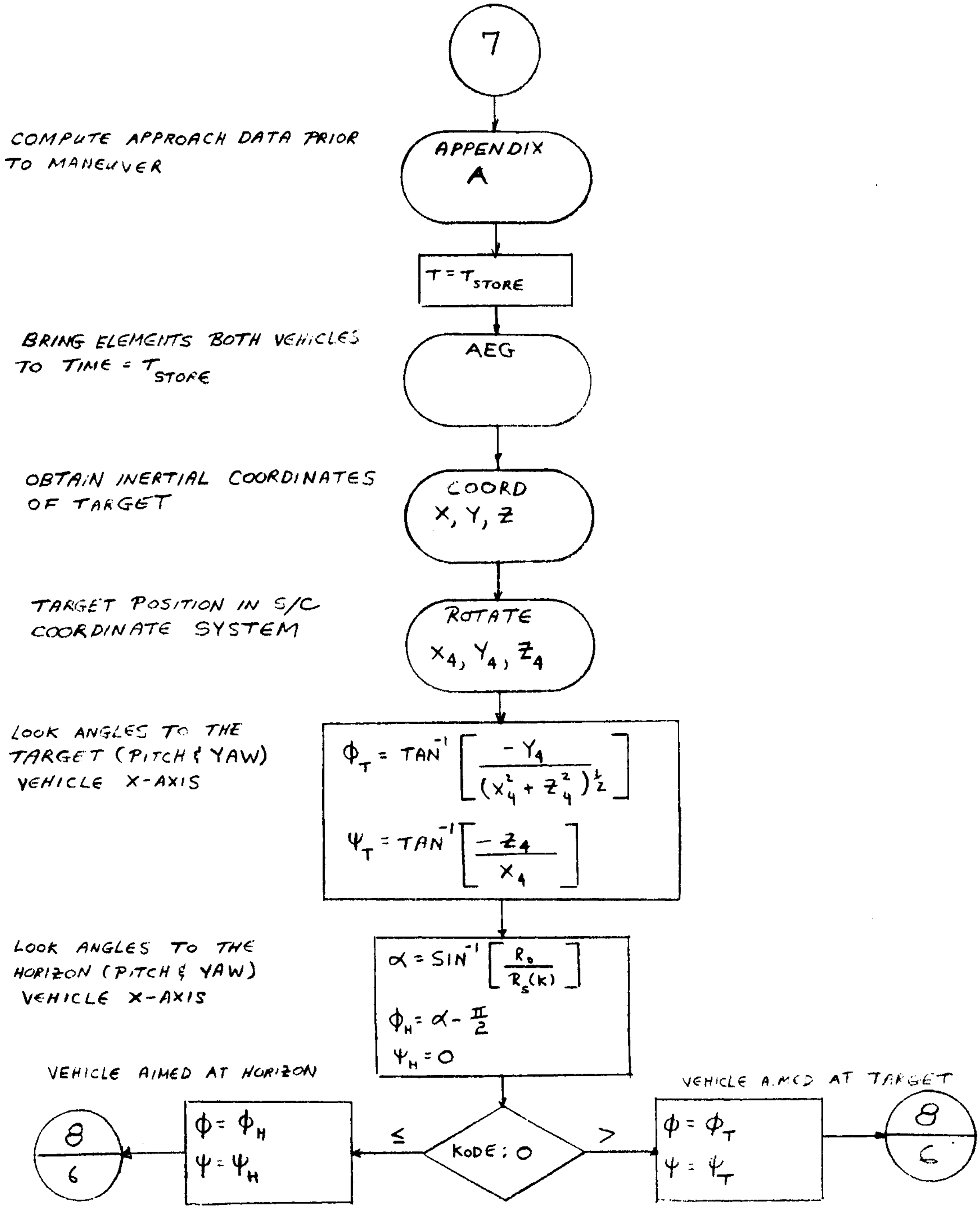
$K = 1$

$\frac{1}{2}$


1
SET THRUSTER CANT ANGLES
$L_c : 1$
LM ≤
$\varepsilon = 0°$
$\varepsilon' = 0°$
> CSM
$\varepsilon = 10°$
$\varepsilon' = 7.25°$
2
$T = T(1, L_c)$
$I_{SP} = I_{SP}(1, L_c)$
$\dot{W} = N_{QUAD} T / I_{SP}$
$\Delta = \frac{WT_K}{e^{\left(\frac{\Delta V_K}{I_{SP}\, g \cos \varepsilon}\right)}}$
WEIGHT APPROXIMATION AFTER FIRST MVR (ASSUMED TO USE X-AXIS RCS THRUSTERS)
IMPULSIVE DIRECTIONAL PITCH AND YAW OF MANEUVER
$\phi' = TAN^{-1}\left[\frac{-\Delta V_Y(K, NS)}{\left\{\Delta V_X^2(K, NS) + \Delta V_Z^2(K, NS)\right\}^{\frac{1}{2}}}\right]$
$\psi' = TAN^{-1}\left[\frac{-\Delta V_Z(K, NS)}{\Delta V_X(K, NS}\right]$
$K = K + 1$
3
3


3
K : 2
≤
WT_k = Δ
2/2
>
k = 1
4
RESET ELEMENTS
a(1) = a'(1)   a(2) = a'(2)
e(1) = e'(1)   e(2) = e'(2)
I(1) = I'(1)   I(2) = I'(2)
g(1) = g'(1)   g(2) = g'(2)
h(1) = h'(1)   h(2) = h'(2)
ℓ(1) = ℓ'(1)   ℓ(2) = ℓ'(2)
K_1(1) = 0   K_1(2) = 0
T = T_S
INITIALIZE AEG FOR BOTH VEHICLES AT THRESHOLD TIME
AEG
K : 1
>
5/4
≤
T = T_B(1, NS)
6/4


5
T = T1
BRING ELEMENTS OF BOTH VEHICLES TO TIME OF FIRST MANEUVER
AEG
OBTAIN INERTIAL COORDINATES OF CHASER
COORD
XLC, YLC, ZLC, ẊLC, ẎLC, ŻLC
OBTAIN NEW ELEMENTS AFTER FIRST MANEUVER
APPLY
ΔVX(1,NS), ΔVY(1,NS), ΔVZ(1,NS)
K1(LC) = 0
INITIALIZE NEW ELEMENTS
AEG
T = TB(2, NS)
6
ADVANCE ELEMENTS TO TIME = T BOTH VEHICLES
AEG
T STORE = T
7
5


7
COMPUTE APPROACH DATA PRIOR TO MANEUVER
APPENDIX A
$T = T_{STORE}$
BRING ELEMENTS BOTH VEHICLES TO TIME = T_{STORE}
AEG
OBTAIN INERTIAL COORDINATES OF TARGET
COORD X, Y, Z
TARGET POSITION IN S/C COORDINATE SYSTEM
ROTATE X_4, Y_4, Z_4
LOOK ANGLES TO THE TARGET (PITCH & YAW) VEHICLE X-AXIS
$\Phi_T = TAN^{-1}\left[\frac{-Y_4}{(X_4^2 + Z_4^2)^{\frac{1}{2}}}\right]$
$\Psi_T = TAN^{-1}\left[\frac{-Z_4}{X_4}\right]$
LOOK ANGLES TO THE HORIZON (PITCH & YAW) VEHICLE X-AXIS
$\alpha = SIN^{-1}\left[\frac{R_0}{R_S(K)}\right]$
$\Phi_H = \alpha - \frac{\pi}{2}$
$\Psi_H = 0$
VEHICLE AIMED AT HORIZON
VEHICLE AIMED AT TARGET
KODE : 0
≤
>
$\phi = \Phi_H$
$\psi = \Psi_H$
$\phi = \Phi_T$
$\psi = \Psi_T$
8 / 6
8 / 6

8

OBTAIN ΔV INCREMENTS IN BODY COORDINATES WITH VEHICLE X-AXIS AIMED AT EITHER TARGET OR HORIZON

$$V'_{80} = \Delta V_X(K,NS)\cos\psi\cos\phi - \Delta V_Z(K,NS)\sin\psi\cos\phi - \Delta V_Y(K,NS)\sin\phi$$

$$V'_{81} = -\Delta V_X(K,NS)\sin\psi - \Delta V_Z(K,NS)\cos\psi$$

$$V'_{82} = \Delta V_X(K,NS)\cos\psi\sin\phi - \Delta V_Z(K,NS)\sin\psi\sin\phi + \Delta V_Y(K,NS)\cos\phi$$

OBTAIN ΔV INCREMENTS IN BODY COORDINATES WITH VEHICLE PITCHED IN ORDER THAT ASTRONAUT MAY VIEW TARGET OR HORIZON

$$V_{80}(K,NS) = V'_{80}\cos(\Delta\phi) - V'_{82}\sin(\Delta\phi)$$

$$V_{81}(K,NS) = V'_{81}$$

$$V_{82}(K,NS) = V'_{82}\cos(\Delta\phi) + V'_{80}\sin(\Delta\phi)$$

PITCH AND YAW OF THE BODY FOR ASTRONAUT TO VIEW TARGET OR HORIZON

$$\phi_{VIEW} = \phi + \Delta\phi$$

$$\psi_{VIEW} = \psi$$

ΔV INCREMENTS IN BODY COORDINATES ROTATED THROUGH ROLL OFFSET OF THRUSTER

$$X_{B_R} = V_{80}$$

$$Y_{BR} = V_{81}\cos\varepsilon' - V_{82}\sin\varepsilon'$$

$$Z_{BR} = V_{82}\cos\varepsilon' + V_{81}\sin\varepsilon'$$

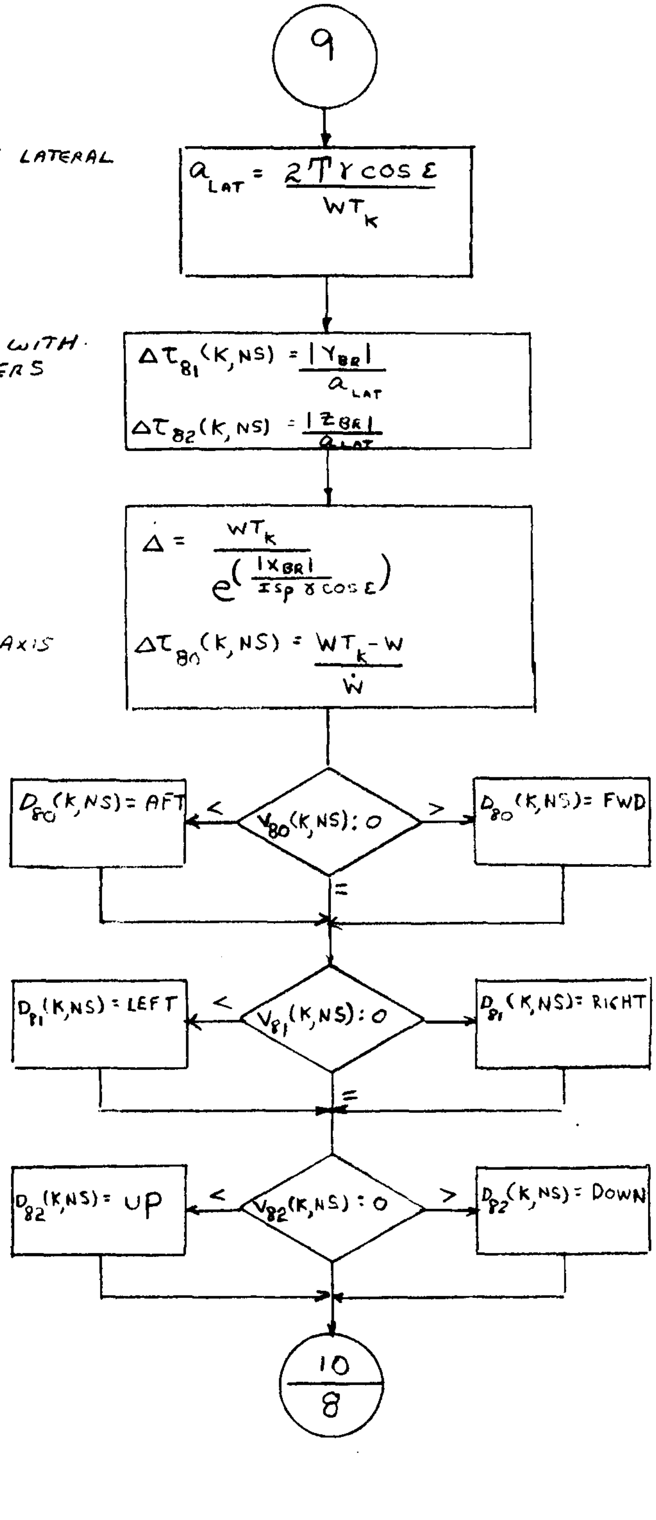
9
7

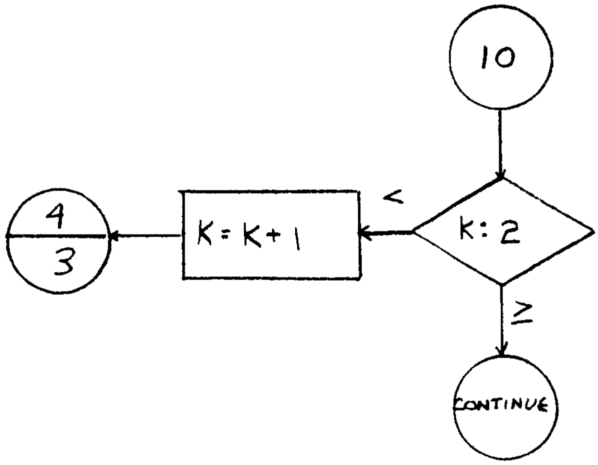
ACCELERATION OF LATERAL THRUSTERS

BURN TIMES WITH LATERAL THRUSTERS

BURN TIME FOR X-AXIS THRUSTER

THRUST DIRECTIONS




10
k : 2
<
K = K + 1
4
3
≥
CONTINUE

APPENDIX C

REVISED LOGIC FOR SUBROUTINE ROTATE

APPENDIX C: REVISED LOGIC FOR SUBROUTINE ROTATE

SUBROUTINE ROTATE
$I, h, U, R_L, X_{IN}, Y_{IN}, Z_{IN}, L, X_{RL}, Y_{RL}, Z_{RL}$

$$\begin{bmatrix} X'_{RL} \\ Y'_{RL} \\ Z'_{RL} \end{bmatrix} = \begin{bmatrix} \cos U_L & \sin U_L & 0 \\ -\sin U_L & \cos U_L & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos I_L & \sin I_L \\ 0 & -\sin I_L & \cos I_L \end{bmatrix} \begin{bmatrix} \cos h_L & \sin h_L & 0 \\ -\sin h_L & \cos h_L & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_{IN} \\ Y_{IN} \\ Z_{IN} \end{bmatrix}$$

$$X_{RL} = Y'_{RL}$$

$$Y_{RL} = R_L - X'_{RL}$$

$$Z_{RL} = Z'_{RL}$$

RETURN

END

REFERENCES

1 Bell, J. A.; and McHenry, E. N.: Logic Changes To The Two-Impulse Processor. MSC Internal Note No. 65-FM-153, Nov. 23, 1965.

2 McHenry, E. N.: Logic and Equations For Real-Time Utilization Of The Two-Impulse Technique. MSC Internal Note No. 65-FM-96, July 21, 1965.

3 Bell, J. A.: Logic For Real-Time Computation of Relative Vehicular Quantities Used By The Terminal Phase Subprocessor And Gemini Computer Checklist Processor. MSC Internal Note No. 64-FM-57, Nov., 1964.